Lasers in Surgery and Medicine 22:46–50 (1998)

# Laser-Induced Thermal Events in Empty and Pulp-Filled Dental Pulp Chambers

**Jason C. Chang and Petra Wilder-Smith***

*Beckman Laser Institute and Medical Clinic, University of California, Irvine, California 92612*

***Background and Objective:*** **The purpose of this investigation was to evaluate:**
**1. thermal events during laser irradiation @2.1 μm of the pulp;**
**2. whether these effects are adequately modeled using an empty pulp chamber/root canal.**
***Study Design/Materials and Methods:*** **In extracted human teeth, pulpal access was prepared and thermocouples placed 2, 3 mm apical to the center of the irradiation spot. Pulp-filled or empty pulp chambers were irradiated using a Ho:YAG laser: Spot Size: 1 mm; Power: 1, 2, 3.5, 4.5W; PRR: 5, 12 Hz; Duration: 10 sec. Thermal measurements were repeated 3×.**
***Results:*** **Thermal trends did not differ significantly and correlated positively with power ($P < 0.01$), PRR ($P < 0.01$), irradiation duration ($P < 0.05$). No significant difference was determined between temperatures in empty and pulp-filled chambers at all parameters at 5 Hz and at 1–2W at 12 Hz ($P < 0.05$, 2-tailed Student's $t$-test). At 12 Hz and >3.5W, pulp chamber temperatures exceeded those in pulpal tissue ($P < 0.05$).**
***Conclusion:*** **Pulp tissues must be present to ensure clinical relevance of thermal measurements. Lasers Surg. Med. 22:46–50, 1998.** 

**Key words: dentin; Ho:YAG; in vitro; root canal; teeth**

## INTRODUCTION

Laser devices have been advocated for a wide range of dental and oro-facial applications, most of them surgical or ablational. The lasers currently available to, or under development for, dental clinicians, predominantly achieve their effects through thermal mechanisms. Typically, localized temperature increases of ⩾100°C are required to achieve tissue vaporization or ablation [1]. The laser energy applied to the target tissues, and heat resulting from this energy transfer, will also affect, to a varying degree, adjacent or underlying tissue structures [2–4]. Heat conduction constitutes the primary mechanism of heat transfer to unexposed tissue structures, whereas the effects of heat convection, e.g., due to blood flow, are relatively negligible due to the low perfusivity of intra-oral tissues [5]. In addition, the pulp tissue is unique in that it is enclosed in hard tissue (dentin and enamel); thus heat dissipation is much reduced and potential for thermal damage is greater.

The extent of collateral damage is, amongst other factors, related to the absorption characteristics of light in the tissues, and the laser parameters and beam configurations used. For most clinical applications, the zone of the thermal damage to adjacent structures should be kept to a minimum, as it may impede wound healing, reduce wound tensile strength, and cause tissue damage or necrosis.

Contract grant sponsor: DOE; Contract grant numbers: DE903-91ER 61227, ONR N00014-90-0-0029; Contract grant sponsor: NIH; Contract grant number: RR01192.

*Correspondence to: Dr. Petra Wilder-Smith, Director, Dental Program, Beckman Laser Institute and Medical Clinic, 1002 Health Science Road, East, Irvine, CA 92612.
E-mail: pwsmith@bli.uci.edu

Accepted 1 October 1997

The oral cavity presents particular challenges to laser usage, as many of its structures are exceedingly sensitive to thermal events. A temperature increase as small as 5.5°C can damage pulpal vitality [6], and the critical temperature for bone injury lies at 47°C, only 10°C above body temperature [7]. In vivo studies on canine teeth of a ferret demonstrated surface resorption of cementum in 28% of cases as result of an 18°C temperature increase [8].

In assessing the safety of intra-oral laser applications, pulpal thermal sensitivity usually defines the lowest threshold of heat tolerance. In addition to the safety issues mentioned above, a sensation of pain is often induced at pulp temperatures which exceed approximately 45°C. Thus, remaining below this temperature will increase the laser's clinical applicability [9].

During thermal safety studies, temperature measurements have often been made at the pulpal surface and within the pulp chamber, usually on extracted human teeth in the absence of pulp tissues. Yet, in the clinical situation, teeth are usually vital, with the complete, healthy pulp in situ. The presence of these soft tissues may well alter thermal events within the pulp chamber resulting from laser irradiation. If this is so, results from past thermal laser safety studies may well be of limited clinical relevance, and future studies must be redesigned to take into account the thermal relevance of in situ pulp tissues.

The aim of this investigation was to evaluate pulpal thermal events resulting from pulsed Ho:YAG irradiation @2.1 µm, and to determine whether these effects can be adequately modeled using an empty pulp chamber and root canal. These studies were performed in extracted human teeth, using empty and pulp-filled pulp chambers.

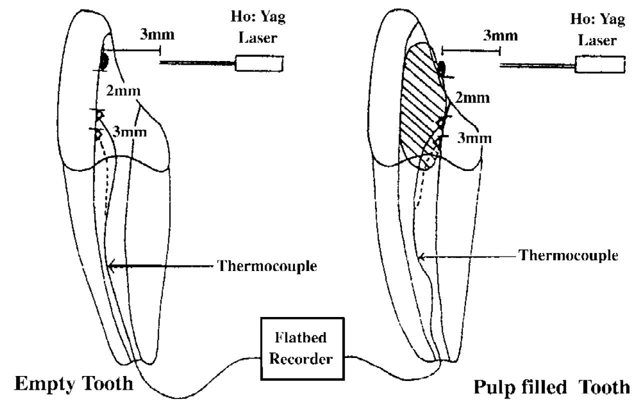


Fig. 1. Experimental configuration.

## MATERIAL AND METHODS

### Samples

In 25 freshly extracted caries-free human incisors and canines of a standardized size (8 mm × 22 mm × 7 mm), a 3 mm diameter pulpal access to the pulp chamber was prepared using conventional methods. The pulpal access was prepared on the lingual surface of the teeth to agree to the conventional root canal treatment procedure; moreover, it is not common to drill on the proximal, distal, or labial surface of the incisors and canines during in vivo root canal preparation. Root canals were enlarged using reamers to size 70, to permit standardized thermocouple placement (Fig. 1). The prepared samples were stored in 0.9% sterile isotonic saline (Sodium Chloride solution). Teeth were mounted using laboratory clamps, as was the laser fiber.

Fresh pulp tissues were extracted from vital human teeth and stored in 0.9% sterile isotonic saline and kept in 5°C cold room; they were returned to room temperature prior to each experiment, when they were inserted into the coronal pulp chamber. As healthy pulp tissue presents one cohesive soft tissue entity, larger in diameter than the root canal, localization and retention of the pulpal tissues at one standardized location was not problematic.

### Laser Device

Irradiation was performed using a Ho:YAG laser emitting at 2.1 µm (New Star Lasers, Auburn, CA). Light was delivered using a 320 µm fiber with surgical handpiece and non-contact tip. The laser beam was directed perpendicularly to the long axis of the tooth at the irradiation spot.

### Laser Parameters

Power: 1, 2, 3.5, 4.5W,
Pulse Repetition Rate: 5, 12 Hz,
Spot size: 1 mm,
Irradiation Duration: 10 sec,
Power was measured using a powermeter (Coherent 210 powermeter, Palo Alto, CA (4303) prior to each irradiation sequence.

### Thermal Measurements

Thermal events were recorded using K-chromel type 70 thermocouples (Omega Engineer-

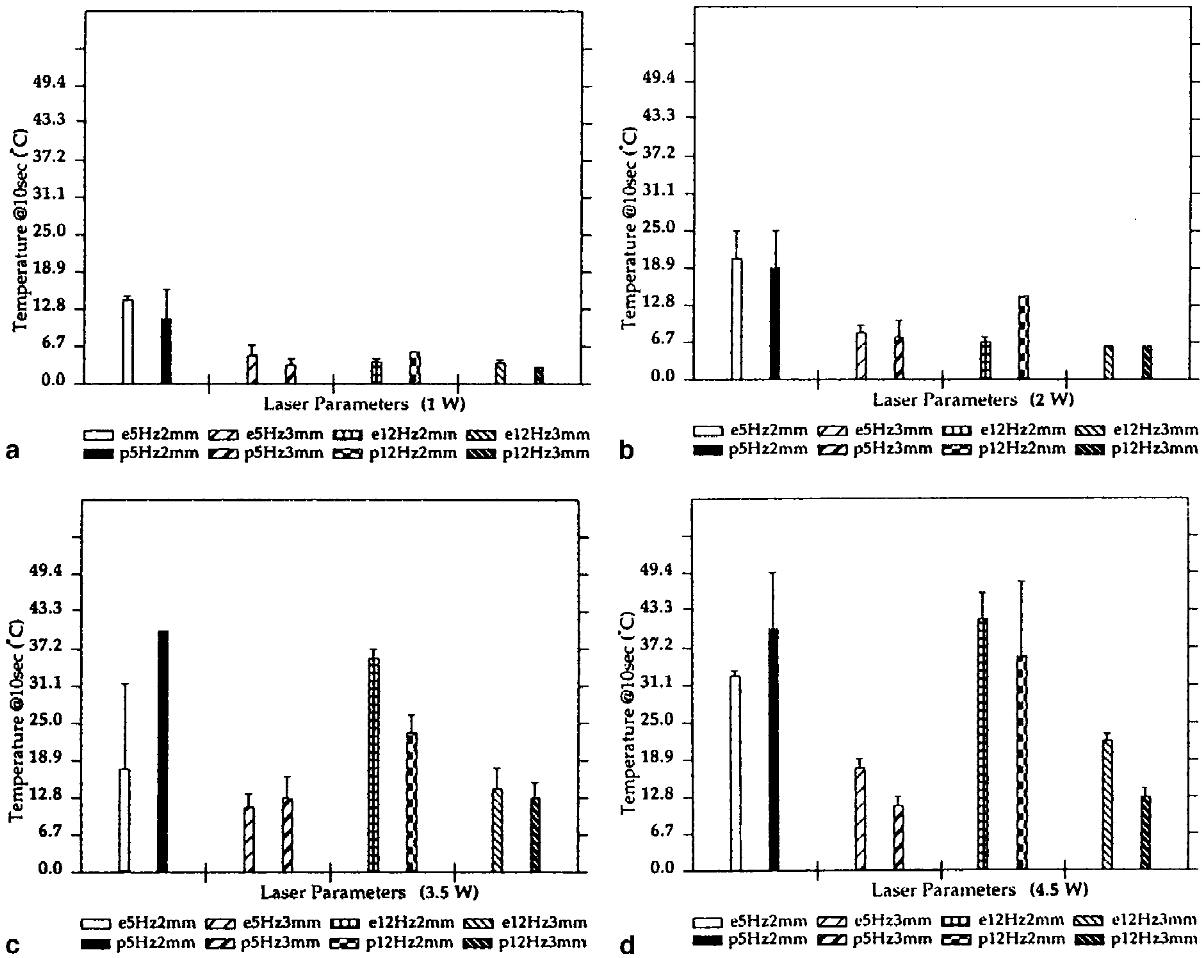


Fig. 2. **a:** Irradiation-induced temperature increases @1W. **b:** Irradiation-induced temperature increases @2W. **c:** Irradiation-induced temperature increases @3.5W. **d:** Irradiation-induced temperature increases @4.5W.

ing Inc., Stamford, Conn.) 2 and 3 mm apical to the center of the irradiation spot on the posterior pulp chamber wall, and 2 and 3 mm apical to the center of the irradiation spot on the anterior aspect of the pulp tissue within the pulp chamber. The change in the thermocouple location was necessary to maintain the linear distance to the irradiation spot equal in both cases. Thermocouple location was confirmed visually and checked with a periodontal probe through the access cavity. Thermocouples were held in place by the strength of the thermocouple wires and attached to the pulp chamber surface with Superglue. Thermal measurements were performed on each tooth in two configurations: 1) with pulp chamber and root canal filled with fresh pulpal tissue, and 2) with empty pulp chamber and root canal. Measurements for each individual tooth and configuration were repeated three times at each laser parameter setting.

## RESULTS

### Observations During Irradiation

Charring was observed at 3.5 and 4.5W within 5 sec of beginning of irradiation, using a frequency of 12 Hz. Moreover, pulpal soft tissues appeared to desiccate and become lighter in color during the course of irradiation at these parameters.

### Thermal Measurements

Irradiation-induced temperatures are depicted in Figure 2a–d. 1) At 5 Hz, laser-induced temperature increases did not differ significantly between the empty pulp chamber and the pulp-filled chamber groups ($P > 0.05$) at all powers used (1W, 2W, 3.5W, 4.5W; Fig. 2a–d). This applied to measurements made at 5 and 10 sec, 2 and 3 mm from the irradiation spot center. 2) At 12 Hz, laser-induced temperature increases did

not differ significantly between the empty pulp chamber and the pulp-filled chamber groups ($P > 0.05$) at powers of 1 and 2W (Fig. 2a,b). This applied to measurements made at 5 and 10 sec, 2 and 3 mm from the irradiation spot center.

Laser-induced temperature increases were significantly greater in the empty pulp chamber than in the pulp-filled chamber groups ($P < 0.05$) at powers of 3.5 and 4.5W (Fig. 2c,d). This applied to measurements made at 5 and 10 sec, 2 and 3 mm from the irradiation spot center.

### Statistics

The two-tailed Student's *t*-test was used to compare thermal events in empty and pulp-filled chambers after 5 and 10 sec irradiation duration.

## DISCUSSION

Irradiation-induced thermal events correlated positively with power ($P < 0.01$), pulse-repetition-rate ($P < 0.01$), and irradiation duration ($P < 0.05$) using the Pearson Correlation Coefficient. The smaller temperature elevation observed at lower powers and pulse-repetition-rate in pulp chamber wall dentin are partly attributed to the weaker absorption of laser light at 2.1 μm in dentin than in soft tissue, as water is the primary absorber [10]. Thus, the greater water content in dental soft tissue (pulp ~70% water) than in hard tissue (dentin ~25% water) is an important determining factor [11]. None of the other major components of dentin (hydroxyapatite, collagen) have an absorption peak at this wavelength.

At 12 Hz and powers $\geqslant$ 3.5W, pulp chamber dentin became significantly ($P < 0.05$) hotter than pulpal tissue filled chamber; this is associated with the development of charring on the dentin surface, leading to increased absorption of laser energy. Other factors may include progressive water loss from pulp tissue during laser irradiation and heat accumulation within the pulp chamber. Thermal loss to the surroundings will also be more extensive during surface irradiation of pulpal tissues, than when target tissues are located deep within the pulp chamber. The observed color change in irradiated soft tissue is probably due to the denaturation of organic matter which leads to higher scattering and lower penetration depth of the laser light [5].

Relatively low power parameters were chosen in this study to remain below the ablation threshold. At higher laser parameters, ablative effects will further complicate events occurring at the irradiation site. In the clinical setting, pulpal blood flow will have negligible heat transporting and dissipating effect, due to the low blood volume of the pulpal vasculature. Heat dissipation is mostly achieved through conduction by the pulpal tissue [9].

These investigations demonstrate that simple measurement of the thermal events within the pulp chamber of extracted teeth does not necessarily provide accurate information on thermal events which will occur in the clinical situation. The presence of pulp tissues within the pulp chamber can alter irradiation-induced thermal changes, to an extent governed by the exact parameters used.

This preliminary investigation into the thermal events resulting from Ho:YAG laser irradiation of the dental pulp demonstrates that use of empty pulp chambers is not appropriate for modeling thermal events during laser treatment in the clinical situation. Further studies are necessary to investigate and quantify the individual effects of the factors listed above, and their interactions.

## ACKNOWLEDGMENTS

Our thanks to New Star Lasers for the loan of their device. My special thanks to ASLMS for their support through a student travel grant for the presentation of this paper at the ASLMS annual meeting in Phoenix, AZ.

## REFERENCES

1. Nelson JS, Berns MW. Basic laser physics and tissue interactions. Cont Derm 1988; 2(2):2–15.
2. Miserendino LJ. Evaluation of thermal cooling mechanisms for laser application to teeth. Lasers Surg Med 1993; 13:83–85.
3. Anic. Laser induced molar tooth pulp chamber temperature changes. Caries Res 1992; 26:165–169.
4. Arrastia AMA. Comparative study of the thermal effects of four semiconductor lasers on the enamel and pulp chamber of a human tooth. Lasers Surg Med 1994; 15: 382–389.
5. Niemz MH. Heat transport. In: "Laser-Tissue Interactions." Berlin, Heidelberg: Springer-Verlag, 1996, pp 58–85.
6. Zach L, Cohen G. Pulp response to externally applied heat. Oral Surg Oral Med Oral Pathol 1965; 19:515–530.
7. Eriksson AR, Albrektsson T. Temperature threshold levels for heat-induced bone tissue injury: A vital microscopic study in the rabbit. J Prosthet Dent 1983; 50:101–107.
8. Saunders EM. In vivo findings associated with heat gen-

eration during thermomechanical compaction of gutta-percha. 1. Temperature levels at the external surface of the root. 2. Histological response to temperature elevation on the external surface of the root. Int Endod J 1990; 23(5):263–274.

9. Niemz MH. Lasers in dentistry. In: Laser-Tissue Interactions. Berlin, Heidelberg: Springer-Verlag, 1996, pp 178–195.

10. Roth KK-F, Duczynski EW, Heide H-J, Struve B. Absorption of infrared radiation by human dental hard substances. Dental Applications of Lasers. SPIE 1993; 2080: 20–25.

11. Pogrel MA, Yen CK, Taylor RC. A thermographic evaluation of the temperatures achieved by a carbon dioxide laser on soft tissues and teeth. Thermology 1988; 3:50–52.